Using the Jets-without-Jets Algorithm to Model MET in an ATLAS Level-1 Trigger Algorithm

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ATLAS EXPERIMENT

Introduction

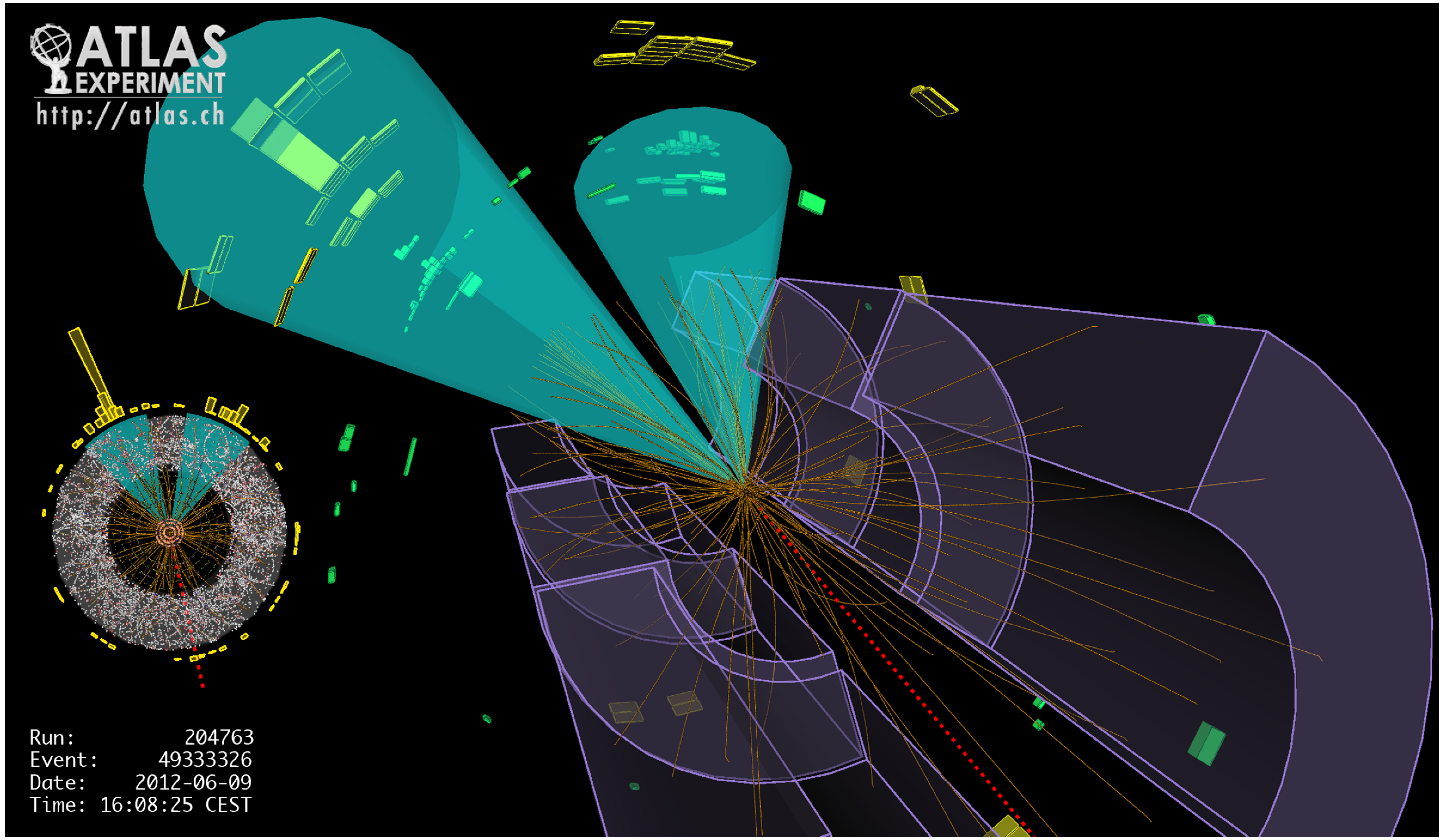
- Motivation
- Introduction to the gFEX
- Introduction to the Jets-without-Jets Algorithm
- Modeling Missing Transverse Energy Using the Jets-without-Jets Algorithm
- Determining the Optimal Form of Missing Transverse Energy
- Conclusion

- This analysis has been performed using simulated data.
  - Signal: $ZH \rightarrow \nu\nu b\bar{b}$
  - Background: MinBias
- "MET Truth" = the truth MET for all stable, interacting particles (excluding muons) within $|\eta| < 5$.

Motivation

- Of the 600 million proton-proton collisions that occur every second within the ATLAS detector (at 7 TeV), only ~200 events can be added to long term storage.
- The ATLAS trigger system performs this reduction in steps by isolating potentially desirable events.
- The ATLAS detector is not capable of directly observing neutrinos, SUSY particles, dark matter and any other particles that do not interact with its detector components.
- Missing Transverse Energy (MET) in an event is used to infer the presence of non-interacting particles.

Event Display for ZH → $\nu\nu b\bar{b}$ Event Candidate

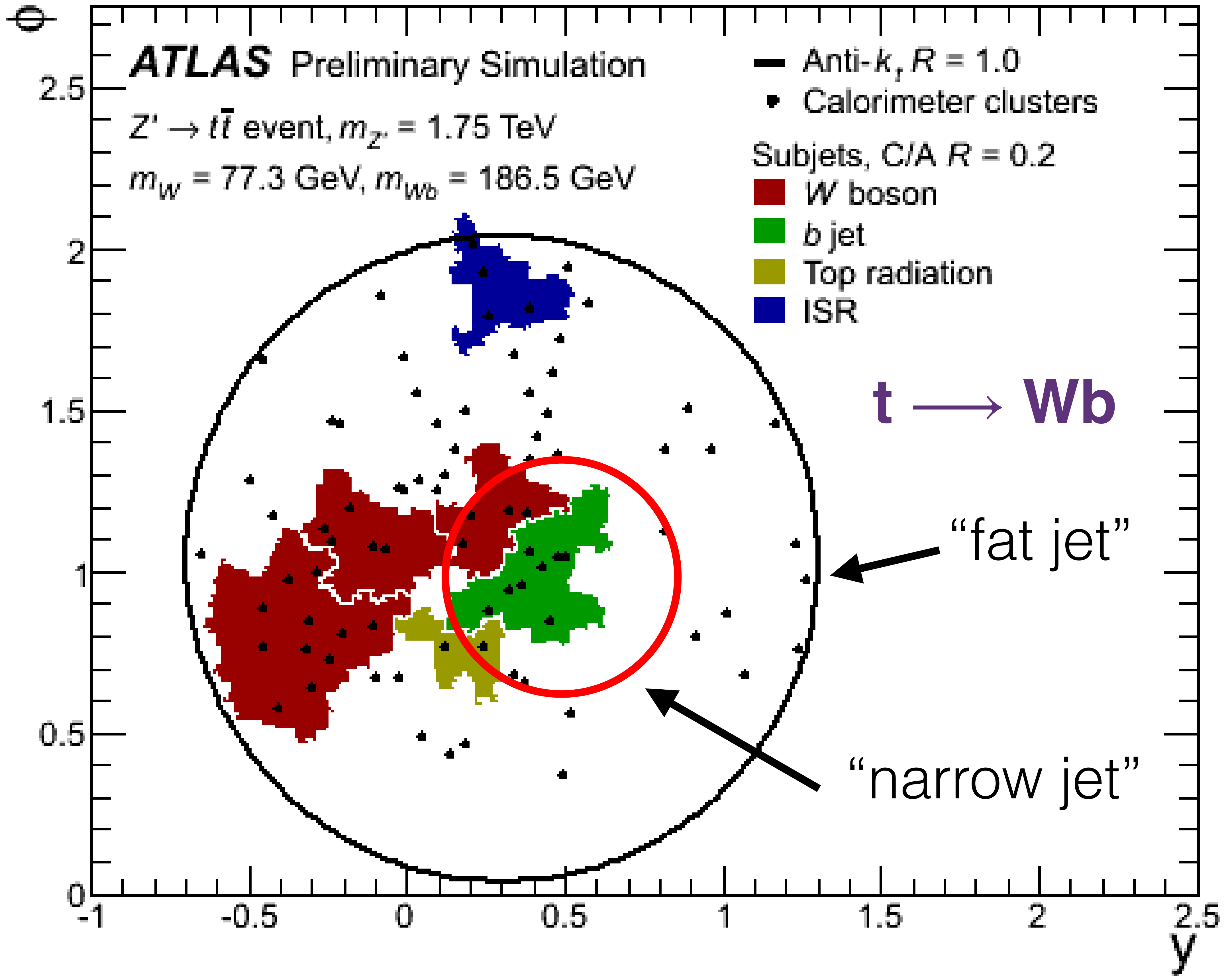


ATLAS-CONF-2012-161

- Current computational requirements result in MET being determined offline. In part this is due to the need to perform complicated jet reconstruction and calibration.
- These studies present a novel alternative approach to constructing MET as the basis for a Level-1 trigger algorithm.

The gFEX (Global Feature Extractor)

- The gFEX is a component that will be incorporated into the upcoming Phase I upgrade of the ATLAS Level-1 Calorimeter Trigger system.
- It will take real time coarse granularity information from the entire calorimetry system and analyze it on a single processor board using three Field Programable Gate Arrays (FPGAs).
- It is designed to help identify the energy signatures associated with the hadronic decays of high momentum particles.
    - The current Level-1 trigger uses narrow jets which work well for the identification of lower p_T particles.
    - The gFEX will allow the acceptance of “fat” jets into the Level-1 trigger which are much better at identifying boosted objects such as W and Z bosons, and top quarks.



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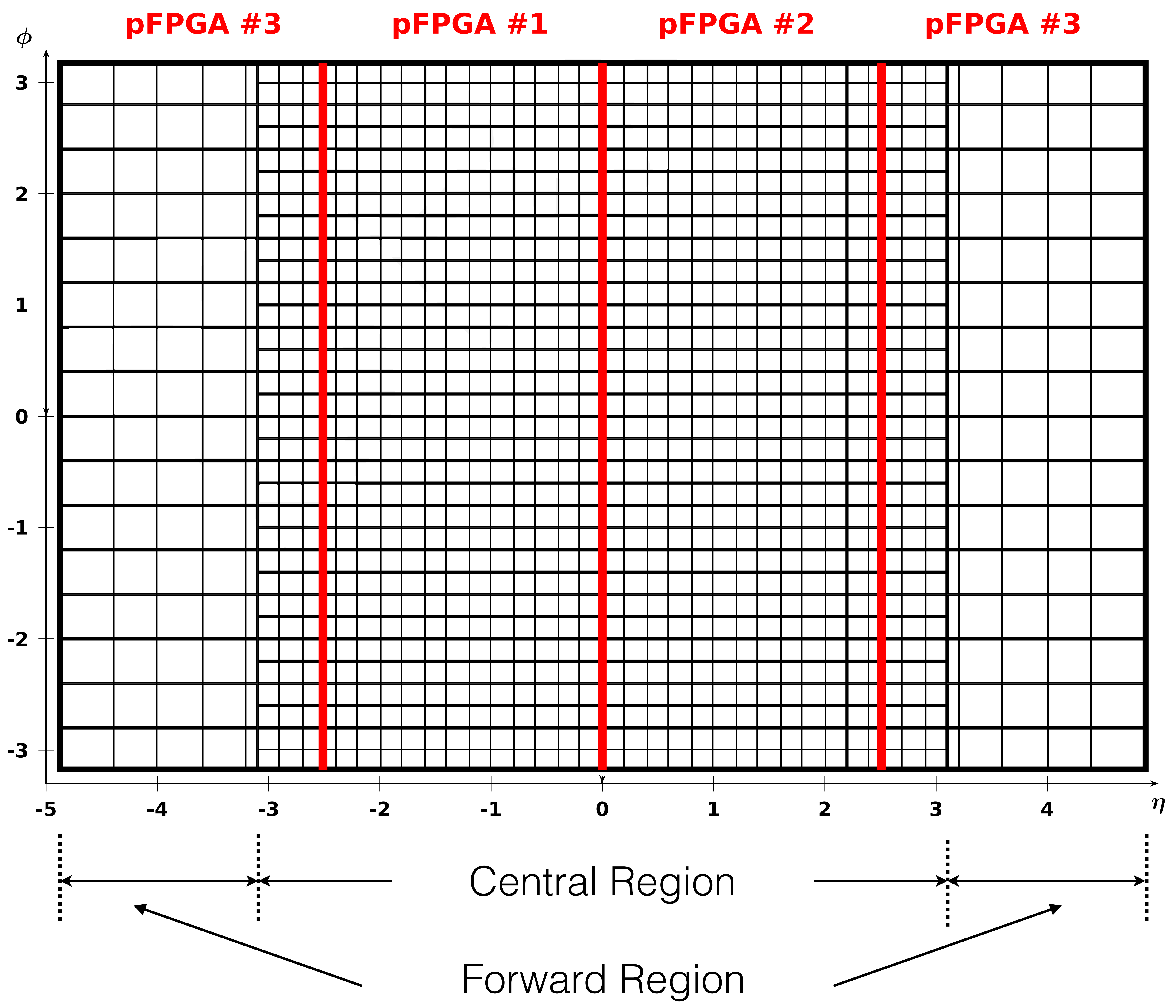
- The gFEX analyzes event level information using a set of coarse granularity cells called gTowers.
- As shown here, the size of a gTower is fixed but depends on its location in the detector.
  - For central region (η < 3.2) the size of a gTower is $\Delta\eta \times \Delta\varphi = 0.2 \times 0.2$
- Because the gFEX incorporates information from the entire event, the gFEX is well suited to the task of quickly calculating Missing Transverse Energy (MET).
- The Jets-without-Jets Algorithm (JwoJ) is one of the algorithms being studied for potential implementation on the gFEX as a quick MET calculator.

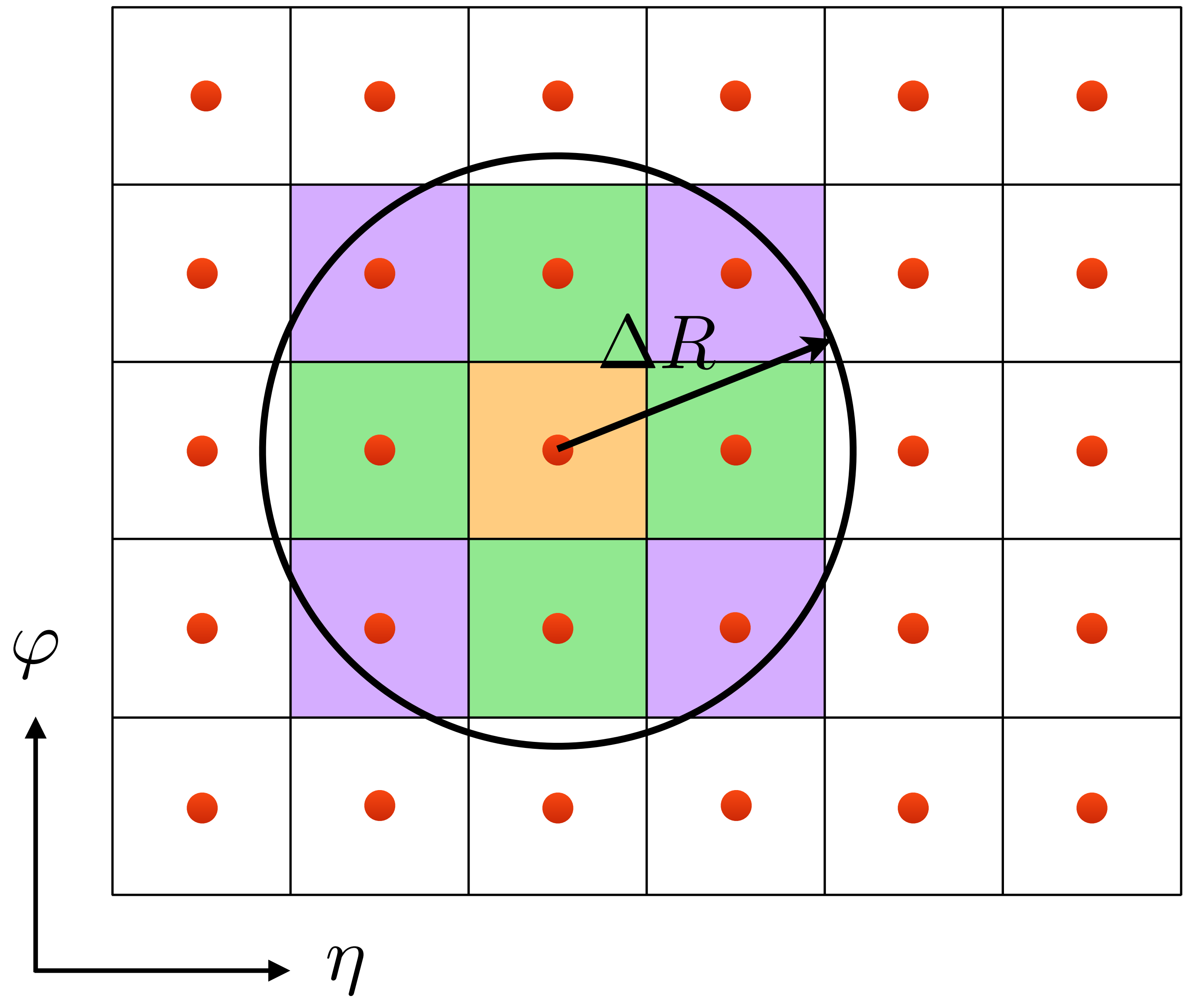
arXiv:1310.7584v2 [hep-ph]



Jets-without-Jets

The Jets-Without-Jets Algorithm:

- **Step 1**: for the i^{th} gTower, sum all transverse energy from the gTowers whose centers are within a given ΔR of the gTower.
- **Step 2**: use these sums to construct,
  - **MHT_{JwoJ}** = magnitude of the vector sum of E_T for all gTowers whose sum is greater than a threshold. ("Hard Term")
  - **MET_{JwoJ}** = magnitude of the vector sum of E_T for all gTowers whose sum is less than a threshold. ("Soft Term")
- **Step 3**: Calculate Missing Transverse Energy (MET).



$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$$

- Other Useful Quantities:
  - **MET_{gT}** = magnitude of the vector sum of E_T for all gTowers in an event. ("Total Term")
  - **Scalar E_T** = scalar sum of E_T for all gTowers in an event.

- Four methods of expressing MET as a weighted sum of JwoJ quantities are being studied.

MET = a MHT_{JwoJ} + c	**MET = a MHT_{JwoJ} + b MET_{JwoJ} + c**
MET = b MET_{gT} + c	**MET = a MHT_{JwoJ} + b MET_{gT} + c**

Modeling MET

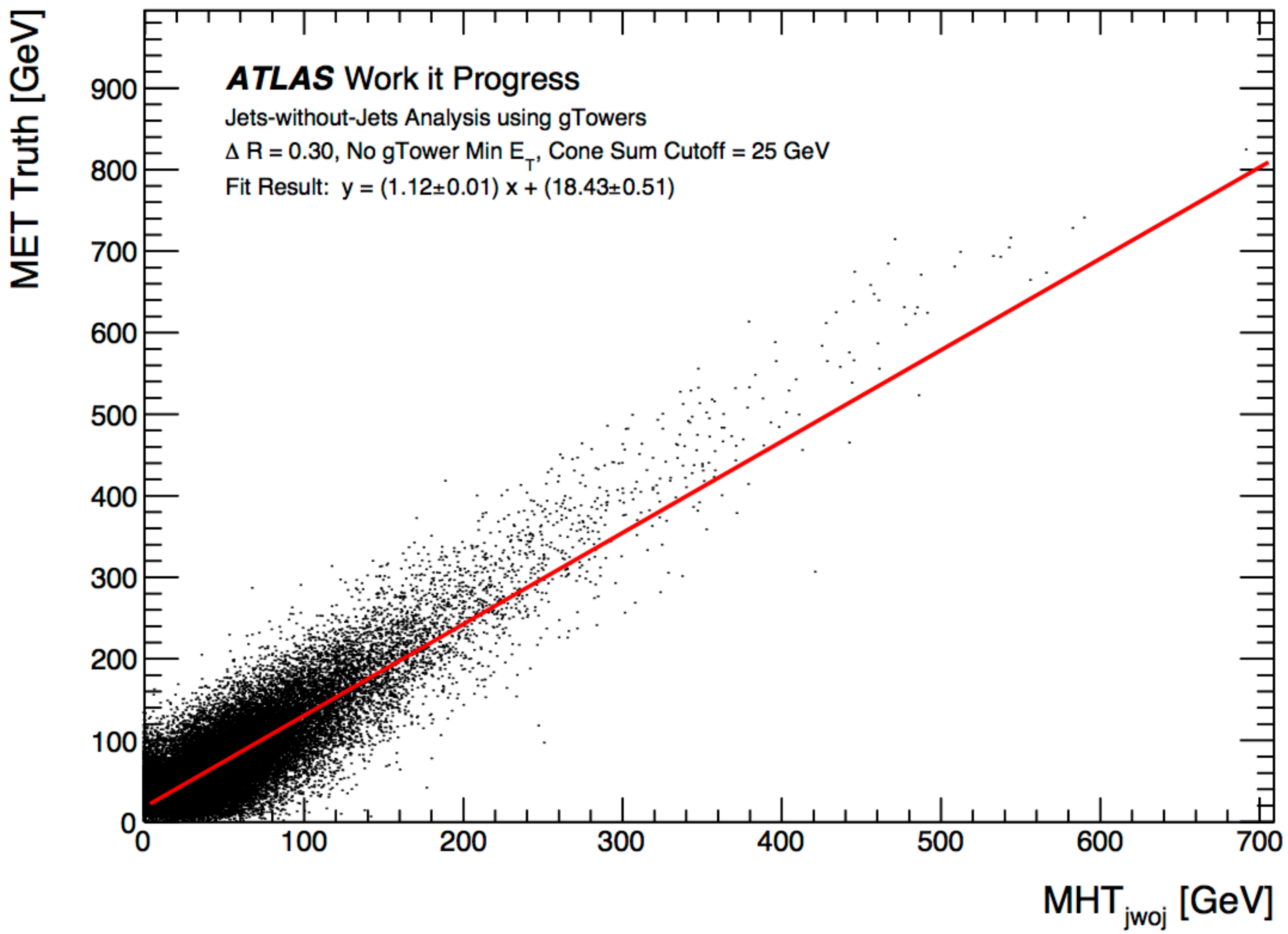
- As a first step in these studies, an attempt was made to model MET in terms of only MHT_{JwoJ} using constant values for “a” and “c”.

$MET = a\ MHT_{JwoJ} + c$

- As can be seen here, using constant values for “a” and “c” does a poor job of modeling MET for the full range of MET values.
- From this it was determined that non-constant values for the coefficients should be used to model MET using JwoJ quantities in the proposed manner.

- To best proceed with the analysis it is important to keep the purpose of these studies in mind.
  - Purpose: Build a Level-1 MET trigger algorithm.
- So, the ideal form of calculated MET should be computationally “simple”.
  - Not a complicated Nth degree polynomial.

MET Truth vs. MHT_{jwoj} for $ZH \rightarrow \nu\nu b\bar{b}$



Modeling MET

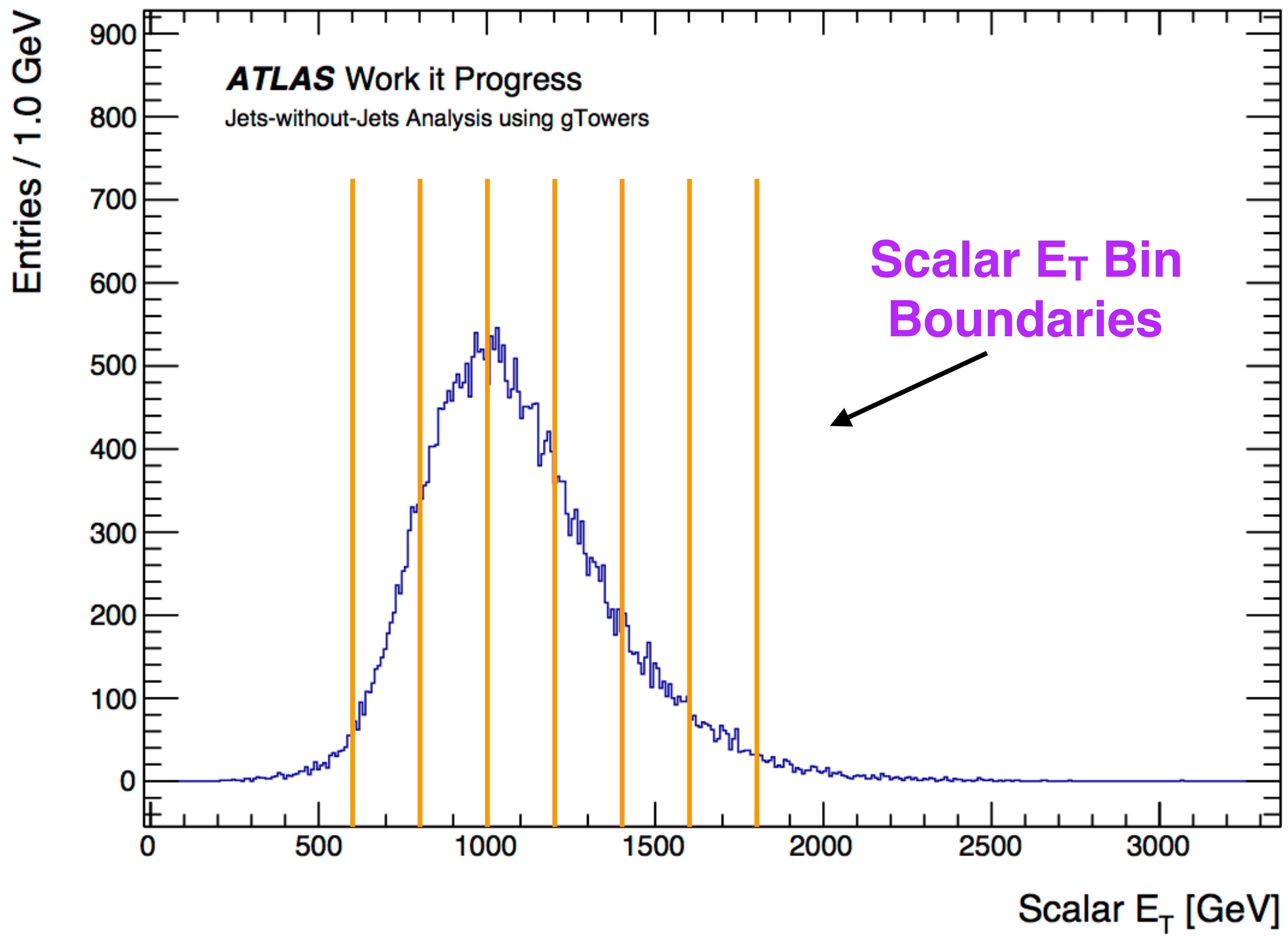
- Seeking a "simple" form of calculated MET, the following method was developed.

Method:

- Bin each of the JwoJ quantities in terms of Scalar E_T.
- Determine the coefficient values for each bin by minimizing,

$$\chi^2 = \frac{1}{N}\sum_{i=1}^{N}(\text{MET Truth}_i - \text{MET}_i)^2$$

Scalar E_T for $ZH \rightarrow \nu\nu b\bar{b}$



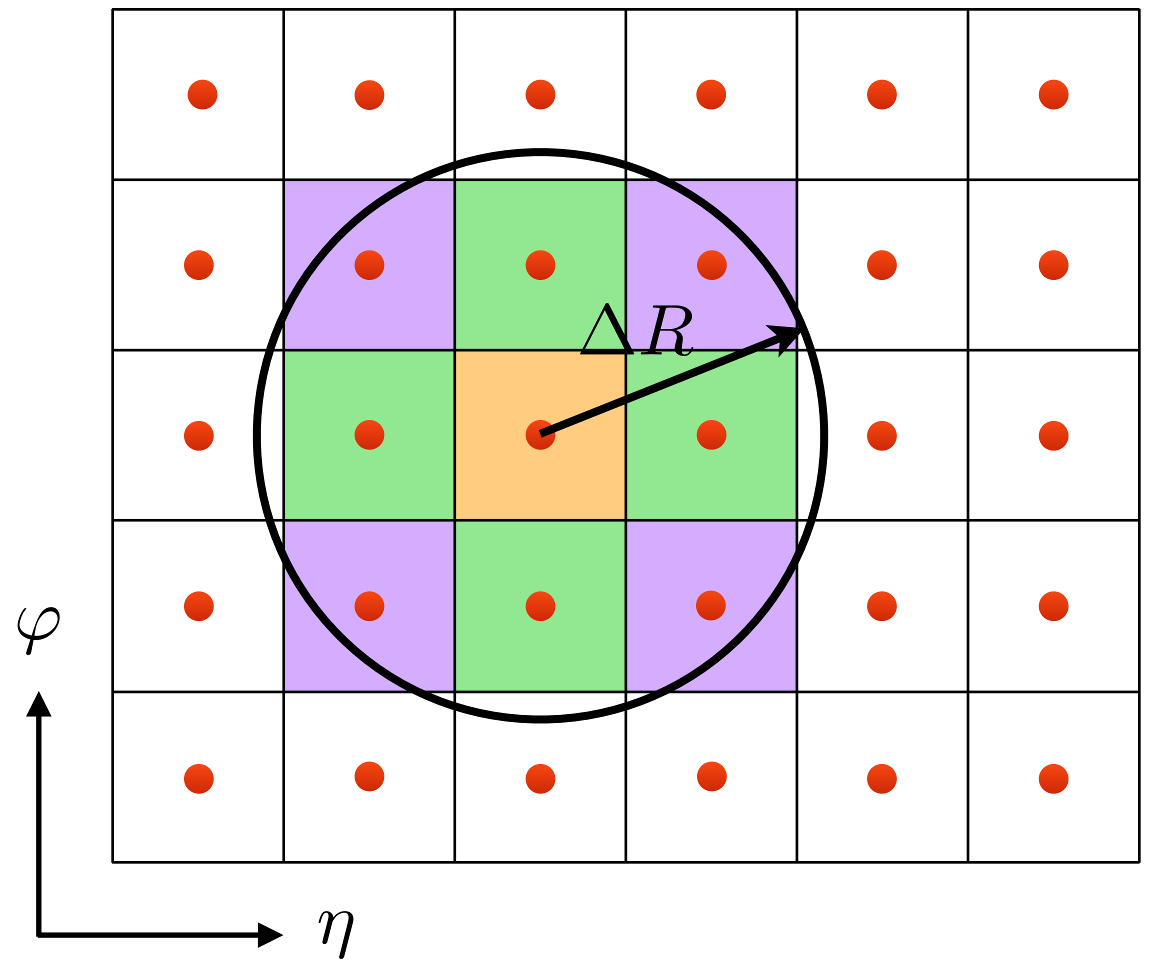
- Binning is performed in terms of Scalar E_T because it is an easily determined quantity (scalar vs. vector). Note that, binning in terms of the other JwoJ quantities produces similar results.
- For a given signal sample, this method produces an independent set of coefficient values for each Scalar E_T bin.
- Using the sets of optimized parameter values it is then possible to compute MET for all events in a sample based on the sample's event-by-event values for Scalar E_T.
- Once optimal values of "a", "b" and "c" have been determined, they will be incorporated into a lookup table that will be used as part of the trigger algorithm.

Analysis Cuts

- A set of analysis cuts exist within the Jets-without-Jets Algorithm.
- Since these cuts affect the relative sizes of the “Hard” and “Soft” terms, they alter the calculation of MET.

Proposed Possible Analysis Cut Values:

- Cone Radius (ΔR): 0.25 or 0.30
- Minimum gTower E_T to be Included in Cone Sum: None, 0 or 1 GeV
- gTower Cone Sum Cutoff: 10, 15, 20, 25 or 30 GeV



- Some of the proposed these adjustments have been rejected for reasons that are not related to performance.
  - For implementation reasons, ΔR = 0.25 (the “cross”) has been rejected in favor of ΔR = 0.30 (the “3x3”).
  - Due to a desire to hold onto the contributions from negative gTowers, no minimum gTower E_T has been chosen.

Determining the Optimal Form of MET

- In this analysis, the following tools are used to determine the optimal method for calculating MET.
  - Resolution
  - Trigger Turn-On Curves
  - ROC Curves
- Using these tools, it has been determined that the best performing analysis cut set includes a cone sum cutoff of 25 GeV for all of the proposed methods of calculating MET.

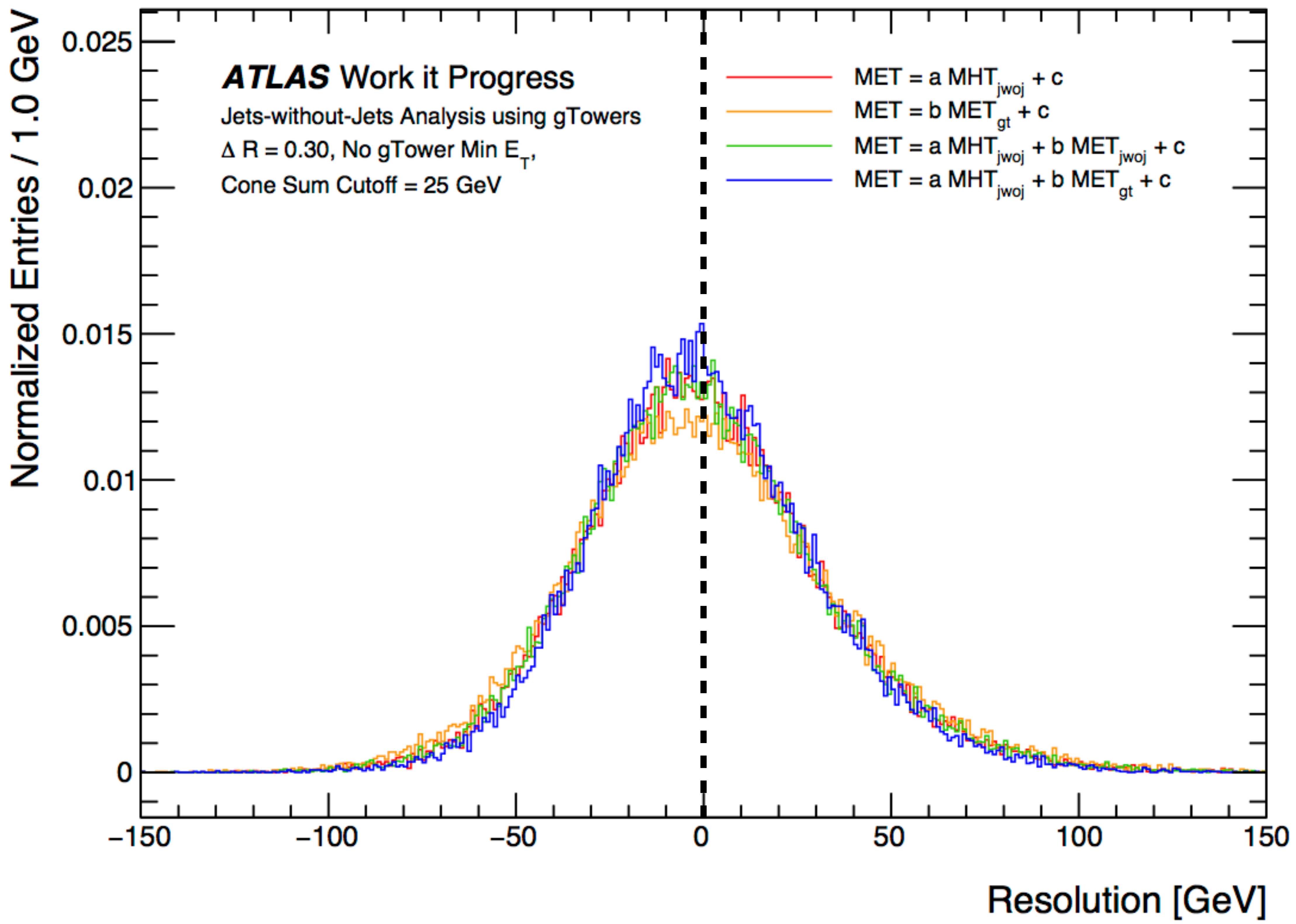
- Resolution is found by computing an event level difference.

Resolution = MET Truth - MET

- After this difference is found for all events in the sample, the Resolution distribution is then fit using a double gaussian.
- Based on the results of these fits, the form of calculated MET that has the best resolution is,

$$\mathbf{MET = a\ MHT_{JwoJ} + b\ MET_{gT} + c}$$

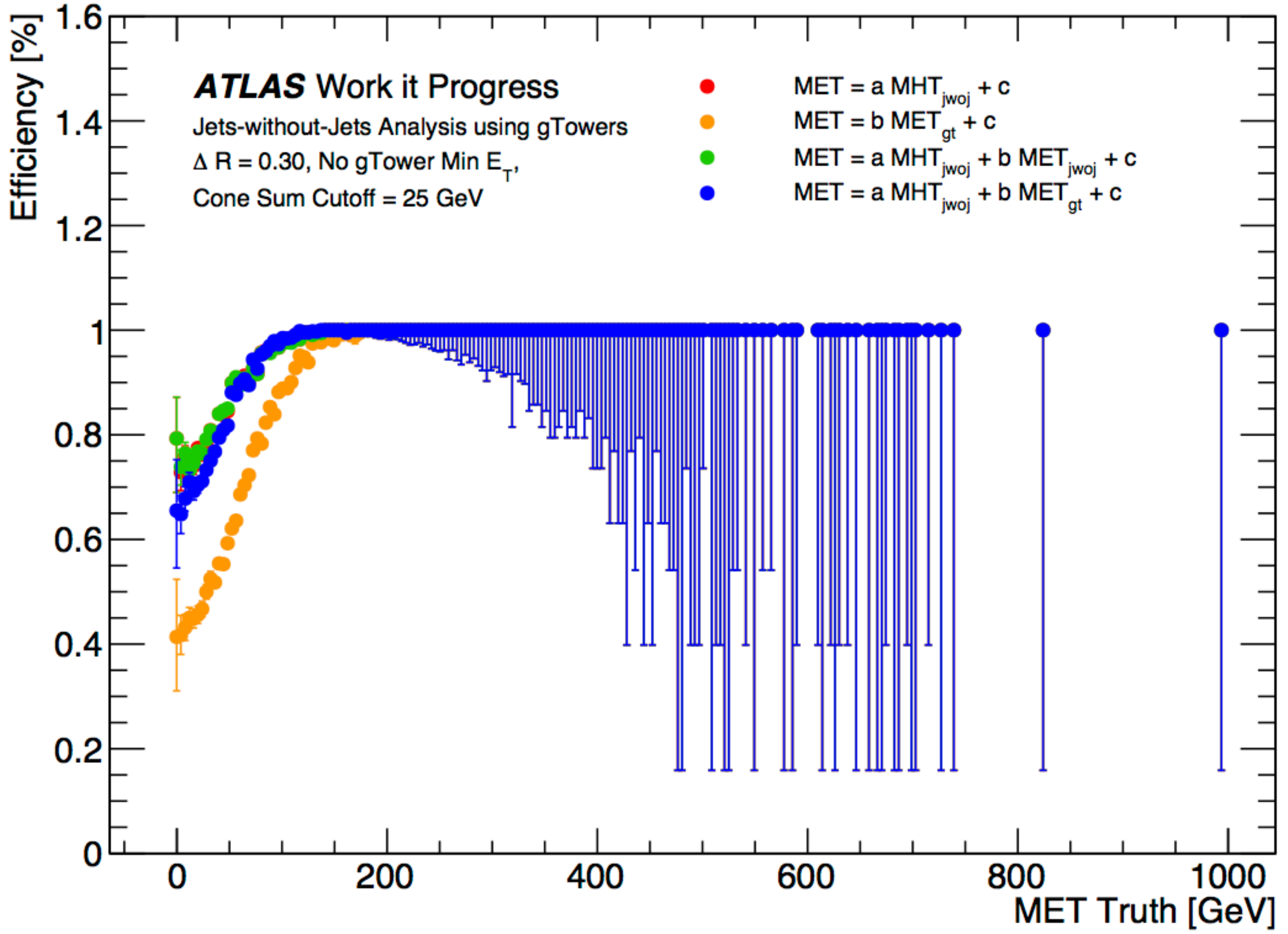
Resolution for ZH → $\nu\nu b\bar{b}$



- For the Trigger Turn-On Curves shown here, the background rates for all of the forms of MET are set to the same value.
- The background rate is found by setting the MET Threshold to 50 GeV for **$MET = b\ MET_{gT} + c$.**
- The resulting curves are fit using a sigmoid function with A = 1. $$y = \frac{A}{1+e^{-k(x-x_0)}}$$
- For a standard trigger, the desired Turn-On curve for a given background rate has the lowest turn on (x_0) and reaches an efficiency of 1.
- For a MET Trigger, the curve should also have the greatest area under the curve at low MET Truth.
- Based on these criteria, the form of calculated MET shown here that has the best turn-on efficiency is,

$MET = a\ MHT_{JwoJ} + b\ MET_{JwoJ} + c$

Trigger Turn-On Curves for ZH → ννbb̄

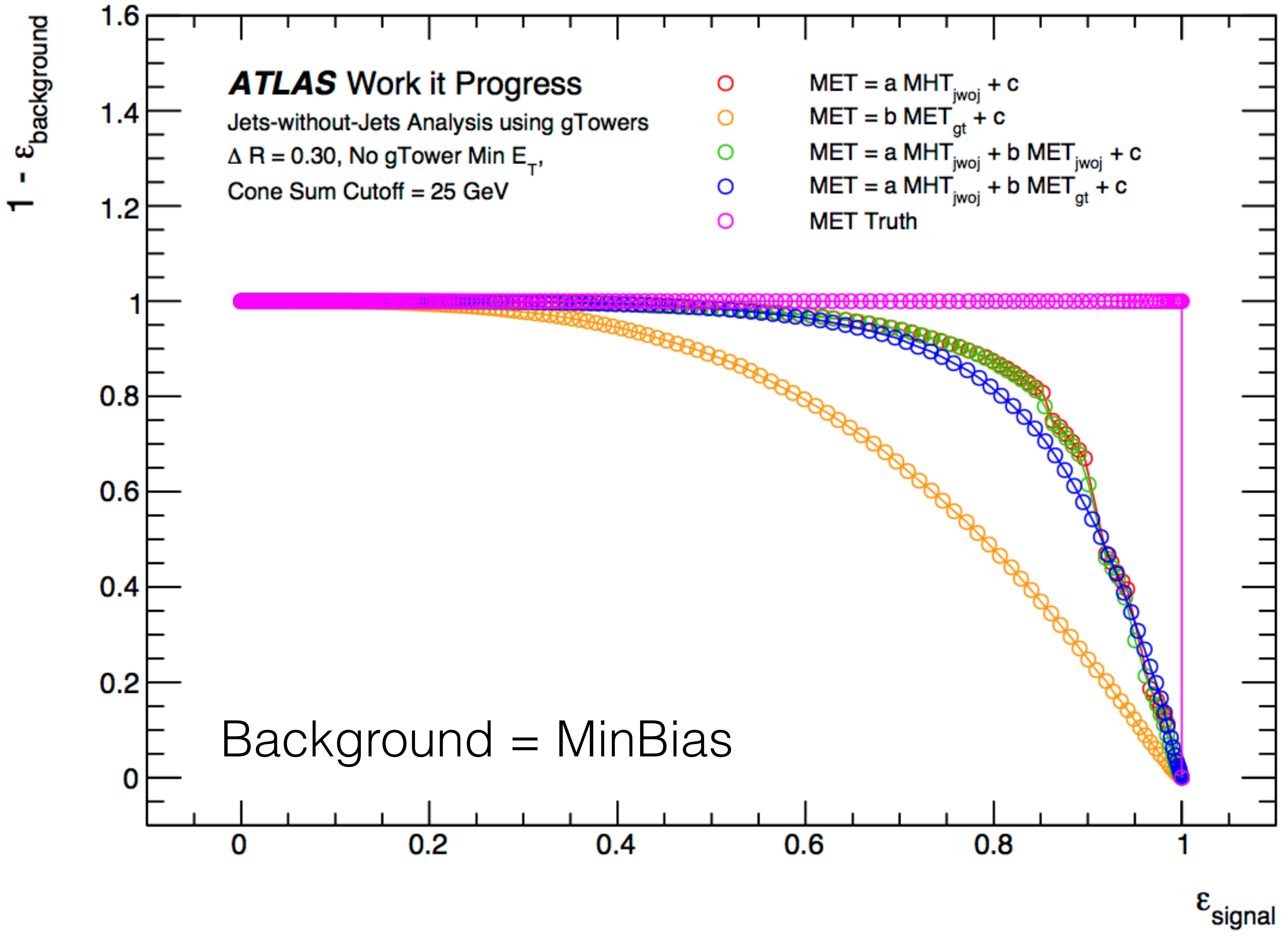


Background = MinBias

- A ROC Curve is an efficiency curve that compares signal acceptance to background rejection.
- For reference, the ROC Curve for **MET Truth** represents the best possible efficiency for the system.
- As shown here, the ROC curves for **MET = a $\mathrm{MHT_{JwoJ}}$ + c** and **MET = a $\mathrm{MHT_{JwoJ}}$ + b $\mathrm{MET_{JwoJ}}$ + c** are discontinuous at high signal efficiency.
- This behavior is caused by two underlying factors.
  - Both forms of MET are highly dependent on $\mathrm{MHT_{JwoJ}}$.
  - The contributions to $\mathrm{MHT_{JwoJ}}$ experience a marked decrease when the cone sum threshold exceeds 20 GeV.
- Taking this into consideration, the form of MET that has the most desirable ROC Curve efficiency is,

MET = a $\mathrm{MHT_{JwoJ}}$ + b $\mathrm{MET_{gT}}$ + c

ROC Curves for ZH → $\nu\nu b\bar{b}$



Conclusion

Current Status

- An approach to calculating MET using the Jets-without-Jets Algorithm and the gFEX has been introduced.
- Using this approach, four methods of calculating MET have been proposed and studied.
- A preliminary "best" form of calculated MET using JwoJ quantities has been determined.
  - Version of Calculated MET: $\mathbf{MET = a\ MHT_{JwoJ} + b\ MET_{gT} + c}$
  - Best Analysis Cut Set: $\Delta R = 0.30$, no gTower minimum ET, gTower cone sum cutoff = 25 GeV
- Similar studies have been performed using other signal and background samples.
- Cross sample comparison has shown strong sample dependence.

Moving Forward

- Ongoing work is being done to remove sample dependence from the method being used to determine MET.
- The emphasis of these studies is shifting from signal acceptance to background rejection. To achieve this, optimization will be performed in the "low" MET region.
- Once parallel calibration and pileup studies are completed, gTower calibration and pileup subtraction will be incorporated into these studies.
- Following the completion of these studies, a Level-1 MET trigger algorithm will be constructed and tested.

Abbreviations

- ATLAS = A Toroidal LHC ApparatuS
- JwoJ = Jets-Without-Jets
- FPGA = Field Programable Gate Array
- gFEX = Global Feature Extractor
- MET = Missing Transverse Energy

Citations

- S. Tang, M. Begel, H. Chen, F. Lanni, H. Takai, W. Wu and the ATLAS Collaboration (2015). gFEX, the ATLAS Calorimeter Level-1 Real Time Processor. ATLAS Note: ATL-DAQ-PROC-2015-059.
- D. Bertolini, T. Chan and J. Thaler (2014). Jet Observables Without Jet Algorithms. eprint arXiv:1310.7584v2 [hep-ph].

Backup